Renal failure after thoracoabdominal aortic surgery

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Purpose: Renal failure remains a common and morbid complication after complex aortic surgery. This study was performed to identify perioperative factors that contribute to postoperative renal failure.

Methods: The perioperative outcomes of 183 patients who underwent thoracoabdominal aortic surgery with supraceliac clamping were reviewed. During the interval from Jan. 1987 to Nov. 1996, thoracoabdominal aneurysm repair was performed in 154 patients (type I, 49 patients [27%]; type II, 21 patients [11.5%]; type III, 55 patients [30%]; type IV, 29 patients [16%]), suprarenal abdominal aortic aneurysm repair in 17 patients (9%), and visceral/renal revascularization procedures in 12 patients (6.5%). Intraoperative management included thoracoabdominal aortic exposure and clamp-and-sew technique with renal artery cold perfusion whenever the renal arteries were accessible (79% of cases).

Results: Relevant clinical features included preoperative hypertension (85%), diabetes mellitus (8%), single functioning kidney (10%), recent intravenous contrast injection (34%), renal insufficiency (creatinine level greater than 1.5 mg/dl; 24%), and emergent operation (19%). Acute renal failure, defined as both a doubling of serum creatinine level and an absolute value greater than 3.0 mg/dl, occurred in 21 patients (11.5%), of whom five required hemodialysis (2.7%). Variables associated with this complication included a preoperative creatinine level greater than 1.5 mg/dl ($p = 0.004$) and a total cross-clamp time greater than 100 minutes ($p = 0.035$). The operative mortality risk (within 30 days; 8%) was significantly increased with renal failure (odds ratio, 9.2; 95% confidence interval, 2.6 to 33; $p < 0.005$).

Conclusions: Renal failure, although uncommon in contemporary practice, greatly increases the risk of early death after thoracoabdominal aortic surgery. The overall incidence of renal failure and dialysis requirement in the present series compare favorably with those reported using other operative techniques, specifically partial left heart bypass and distal aortic perfusion. These data suggest that patients who have preoperative renal insufficiency are prone to postoperative renal failure. Furthermore, regional hypothermic perfusion and minimal clamp times are important elements in the prevention of renal failure after thoracoabdominal aortic surgery. (J Vasc Surg 1997;26:949-57.)

Renal failure (RF) remains a significant and oftentimes lethal complication in patients who have undergone complex aortic surgery. Major advances have been made with respect to perioperative surgical and anesthetic care in patients who undergo thoracoabdominal (TA) aortic surgery. Yet Svensson et al.[1] identified spinal cord ischemia and postoperative RF as the principle unsolved problems that complicate thoracoabdominal aneurysm (TAA) repair. These patients may be prone to postoperative RF given their multiple risk factors, including advanced age, often antecedent renal insufficiency, and atherosclerotic renal artery stenosis. Furthermore, patients may undergo significant intraoperative hemodynamic changes with thoracic aortic cross-clamping. Despite varying definitions, contemporary reports reveal an incidence of RF from 9% to 40% in patients who undergo TAA repair, with a significant increase in the postoperative mortality rate in these patients.[2-10] Specific adjuncts to prevent RF after TAA have been attempted, with only marginal improvements.[11,12] There is continued controversy as to the optimal intraoperative management to decrease the incidence of postoperative RF, and no consensus exists. Thus, in attempting to elu-

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Table I. Thoracoabdominal aortic operations in 183 patients

	n (%)
TAA type I	49 (27)
II	21 (11.5)
III	55 (30)
IV	29 (16)
Suprarenal AAA	17 (9)
Visceral/renal revascularization	12 (6.5)

AAA, Abdominal aortic aneurysm.

cidate factors associated with RF after TA surgery, we reviewed the perioperative outcome in 183 patients who underwent TA surgery to identify variables that were associated with postoperative RF.

PATIENTS AND METHODS

From January 1987 to November 1996, 183 patients underwent TA aortic surgery on the senior author's (RPC) service. In this group, 154 (84.5%) underwent TAA repair, whereas the remainder underwent total abdominal aortic repair, as detailed in Table I. Inclusion criteria for this group were patients who underwent similar physiologic insult with TA exposure and supraceliac aortic clamping. Specifically excluded were (1) juxtarenal or pararenal aortic aneurysm repairs that required suprarenal, but not supraceliac clamping; and (2) renal artery reconstruction procedures performed without supraceliac clamping. Although these procedures were not all TAA repairs, those that were not (n = 29) were complex suprarenal and visceral reconstruction procedures that required both TA exposure and supraceliac clamping. Although this subgroup had a 0% mortality rate (vs 8.2% overall), their rate of RF, the focus of this paper, was actually higher (13.8% vs 11.5% overall), and thus their inclusion was thought appropriate in this study. All clinical, perioperative, and demographic data were obtained through review of original hospital and physician records or from a vascular surgery database. Of note, information on patients before 1992 was abstracted from medical records, and thereafter appropriate information was gathered prospectively in a continuously maintained database.

Definitions. Classification of TAAs followed the schema as outlined by Crawford et al.[13]: type I, entire descending and upper abdominal aorta; type II, entire descending and abdominal aorta; type III, variable extents of descending and abdominal aorta; and type IV, entire abdominal aorta with the graft carried proximal to the celiac axis. The level of the proximal graft distinguished type IV TAA repair versus suprarenal abdominal aortic aneurysm repair. Emergent operation was defined as one that took place within 24 hours of admission for a symptomatic aneurysm. Preoperative expansion, rupture, and dissection were documented by radiologic studies, including computed tomographic scanning, magnetic resonance imaging, and angiography. The latter two conditions were confirmed during the operation. Patients with a single functioning kidney were defined as meeting one of the following criteria: (1) surgically or congenitally absent kidney; (2) no visible nephrogram on contrast arteriogram; or (3) less than 10% of total renal function in a kidney as assessed by Technicium 99 renal scintigraphy. Renal artery stenosis was defined as a > 50% lesion as documented by contrast arteriography. Patients grouped under "recent intravenous contrast injection" underwent contrast arteriographic examination within 5 days of their operation. Intraoperative management in all patients included a clamp-and-sew technique with expeditious reimplantation of patent intercostals in the T9-L1 region and visceral vessels. Patients received 25 g mannitol before aortic cross-clamping. Renal ischemic time was defined as the time needed to reperfuse at least one kidney. Because of the operative approach using a left TA incision, the right kidney was the first kidney to be reperfused in almost all patients except in some type I TAA repairs, in which perfusion was established to both kidneys simultaneously. Renal artery cold perfusion (RACP) was used whenever the renal arteries were accessible (79% of cases). The formulation of the perfusate includes 25 g mannitol and 1 g methylprednisolone per liter of iced (4° C) Ringer's lactate. Bolus infusion (250 ml) of perfusate was instilled into renal artery orifices, followed by continuous drip infusion of the same until arterial flow was reestablished. Total aortic cross-clamp time was defined as the time until all clamps were off and the legs were reperfused. Intraoperative hypotension was defined as systolic blood pressure being less than 70 mm Hg for longer than 10 minutes despite pharmaceutical maneuvers, the reapplication of the crossclamp for hypotension, or cardiopulmonary arrest. Postoperative management included monitoring in the intensive care unit with indwelling systemic arterial and pulmonary arterial catheters until the patient was extubated and did not show any evidence of cardiac or hemodynamic instability. Baseline creatinine levels were documented as the nearest preoperative value before the operative date. Serum creatinine levels were measured on a daily basis until the peak value was reached

Table II. Demographic and clinical factors of patients who underwent thoracoabdominal surgery (n = 183)

		n(%)
Mean age (yr)	70 ± 9	
Gender		
Male		96 (52.5)
Female		87 (47.5)
Coronary artery disease		123 (67)
Hypertension		155 (85)
Diabetes mellitus		15 (8)
Single functioning kidney		19 (10)
Renal artery stenosis		
Single		48 (26)
Bilateral		24 (13)
Recent IV contrast		62 (34)
Baseline creatinine		
< 1.5 mg/dl		140 (76)
1.5 to 3.0 mg/dl		38 (21)
> 3.0 mg/dl		5 (3)
Emergent operation		34 (19)
Preoperative aneurysm expansion		37 (20)
Rupture		20 (11)
Aortic dissection		34 (19)

IV, Intravenous.

Table III. Intraoperative data in patients who underwent thoracoabdominal aortic surgery

		n (%)
Use of RACP		144 (79)
Visceral endarterectomy		30 (16)
Right renal artery		
Bypass		1 (0.5)
Endarterectomy		29 (16)
Left renal artery		
Bypass		119 (65)
Endarterectomy		11 (6)
Nephrectomy		1 (0.5)
Clamp times		
1st kidney (min)	43 ± 14	
2nd kidney	54 ± 19	
Total	68 ± 23	
Operation duration (min)	304 ± 89	
Intraoperative hypotension		26 (14)
Intraoperative deaths		3 (1.6)

Table IV. Stratification of patients according to renal dysfunction

	n (%)
0% to 50% elevation in baseline creatinine level	91 (49.7)
50% to 100% elevation in baseline creatinine level	47 (25.7)
>100% elevation in baseline creatinine level	24 (13.1)
Doubling + creatinine >3.0 mg/dl	16 (8.7)
Dialysis	5 (2.7)

and there was a downward trend. Postoperative renal function was stratified into the following categories: (1) creatinine elevation: less than 50% above baseline creatinine level; 2) creatinine elevation 50% to 100% above baseline level; (3) doubling of creatinine level, but peak less than 3.0 mg/dl; (4) acute RF: doubling of creatinine level and creatinine level greater than 3.0 mg/dl; and (5) patients who required dialysis. The last two were grouped together as significant postoperative RF.

Statistical analyses. All patient data were compiled on a spreadsheet (Excel, Microsoft Corp., Redmond, Wash.), and computations were performed on a DEC VAX 11780 computer (Digital Equipment Corp., Maynard, Mass.). Frequency tables were analyzed for statistical significance with the Pearson χ^2 test or Fisher's exact test. Univariate and multivariate statistical analyses were carried out using Systat software package (SPSS Inc., Chicago). A p value less than 0.05 was considered to indicate a statistically significant difference.

RESULTS

Demographic and salient clinical features in these 183 patients are displayed in Table II. Of note, 24% of patients had preoperative renal insufficiency with creatinine levels greater than 1.5 mg/dl, and five patients had extreme creatinine level elevation (>3.0 mg/dl). Also, renal artery stenosis was found in 39% of patients; one third of these had bilateral stenoses. Intravenous contrast material was administered at angiography in one third of patients within 5 days before the operation. All patients underwent surgery in a standardized fashion as described in the Methods section, and pertinent intraoperative data are shown in Table III. RACP was used whenever the renal arteries were accessible (79% of patients), but renal artery cannulation and RACP was avoided whenever endarterectomy was performed. Endarterectomy was needed as an adjunctive measure for the right renal artery in 16% of patients, whereas left renal artery reattachment was managed with a bypass graft in 65% of patients. In 26 patients (14%) intraoperative hypotension was present, and three of the 183 patients died in the operating room. The intraoperative deaths were excluded from further analysis with regard to RF. Patients were stratified with regard to their renal function after operation (Table IV). Virtually all patients were found to have an elevation in their serum creatinine level, but in half of the patients this elevation was less than 50% from baseline values and remained without clinical sequelae. Another 71 patients (39%) had elevations in serum creatinine level that required close observation and frequent

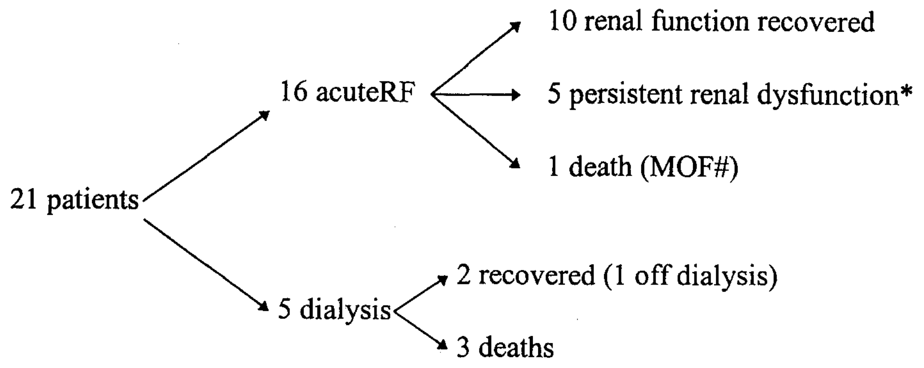

Fig. 1. Outcome of patients with significant renal failure. *Creatinine level greater than 2.0 mg/dl at time of discharge. #Multiple organ failure.

Table V. Univariate analysis of variables examined for association with postoperative RF

Variable	*Without RF*	*With RF*	*p*
All patients (n = 180)	159	21	
Age >70 yr	86 (54)	15 (71)	0.132
Hypertension	136 (86)	16 (76)	0.267
Diabetes mellitus	11 (7)	3 (14)	0.236
Recent IV contrast	55 (34)	7 (33)	0.894
Renal artery stenosis	56 (35)	6 (29)	0.547
Single functioning kidney	17 (11)	2 (10)	0.870
Baseline creatinine >1.5 mg/dl	31 (19)	10 (48)	0.004
Emergent operation	27 (17)	6 (29)	0.197
Aortic dissection	30 (19)	2 (10)	0.293
Ruptured aneurysm	15 (9)	4 (19)	0.178
TAA types I and II	62 (39)	7 (33)	0.616
Use of RACP	125 (79)	16 (76)	0.758
Intraoperative hypotension	18 (11)	5 (24)	0.107
Cross-clamp to kidney >60 min	15 (9)	3 (14)	0.486
Total cross-clamp time >100 min	14 (9)	5 (24)	0.035
Operation duration >300 min	39 (25)	7 (33)	0.385

IV, Intravenous.

Table VI. Univariate analysis of variables examined for association with operative death

Variable	*No. of survivors (%)*	*No. of deaths (%)*	*p*
All patients (n = 183)	168	15	
Age >70 years	93 (55)	10 (67)	0.398
Diabetes mellitus	13 (8)	2 (13)	0.449
Renal artery stenosis	59 (35)	4 (27)	0.509
Single functioning kidney	19 (11)	0 (0)	0.169
Baseline creatinine >1.5 mg/dl	36 (21)	7 (47)	0.027
Emergent operation	28 (17)	6 (40)	0.026
Ruptured aneurysm	16 (9)	4 (27)	0.041
TAA types I and II	64 (38)	6 (40)	0.884
Intraoperative hypotension	17 (10)	9 (60)	<0.0001
Total cross-clamp time >100 min	18 (10)	5 (33)	0.011
Cross-clamp to kidney >60 min	16 (10)	4 (27)	0.041
Postoperative renal failure	15 (9)	6 (40)	<0.01

volume and renal assessment. This often included continued intensive care unit monitoring with pulmonary arterial catheters, frequent serum electrolyte determination, and the occasional use of a nuclear medicine renal scan if renal arterial flow was questioned. RF occurred in 21 patients (11.5%), and five patients required hemodialysis, of whom three eventually died. The cause of death in the three patients who died on dialysis included a combination of multiorgan failure and bleeding in the first patient, respiratory failure in the second patient, and multiorgan failure in the third patient. Fig. 1 displays the outcome of patients who had significant RF (acute RF and dialysis), and these 21 patients were used as a group for the univariate analyses.

Univariate analyses of variables that were examined for association with postoperative RF are displayed in Table V. Among the factors that are evident to the surgeon before operation, only baseline renal insufficiency (preoperative creatinine level > 1.5 mg/dl) was predictive of postoperative RF. Of 41 patients who had preoperative renal insufficiency, postoperative RF developed in 10 (25%). Total cross-clamp time (until all cross-clamps were taken off) greater than 100 minutes was the sole significant intraoperative factor associated with postoperative RF, and intraoperative hypotension approached significance. Interestingly, other variables that were examined and were found not to be associated with postoperative RF included recent intravenous contrast injection, patients with only one functioning kidney, and emergent operations. After logistic re-

Table VII. Renal dysfunction after thoracoabdominal aortic surgery

	Year	*n*	*Renal failure n(%)*	*Definition of renal failure*	*Dialysis n(%)*
Schmidt[2]	1990	40	7 (17)	Doubling of creatinine level	2 (5)
Fox[3]	1991	51	NR		2 (4)
Golden[4]	1991	57	23 (40)	> 1.0 mg/dl increase in creatinine level	NR
Cox[5]	1992	120	35 (29)	Creatinine level > 2.0 mg/dl	33 (27)
Hollier[6]	1992	150	14 (9)	Doubling of creatinine level	6 (4)
Svensson[1]	1993	1509	269 (18)	Creatinine level > 3.0 mg/dl or dialysis	136 (9)
Schepens[7]	1994	85	NR		12 (14.1)
Coselli[8]	1994	372	54 (14.5)	Creatinine level > 3.0 mg/dl or dialysis	NR
Acher[9]	1994	110	NR		3 (2.7)
Grabitz[10]	1996	260	NR		27 (10.4)
Present series	1997	183	21 (11.5)	Doubling of creatinine level & creatinine level > 3.0	5 (2.7)

gression analyses, preoperative creatinine level greater than 1.5 mg/dl (odds ratio [OR], 4.0; 95% confidence interval [CI], 1.5 to 10.5; $p < 0.01$) and total cross-clamp time greater than 100 minutes (OR 3.6; 95% CI, 1.1 to 12.0; $p < 0.05$) were found to be significant independent predictors of postoperative RF.

Univariate analyses of variables examined for association with operative death (Table VI) revealed that important factors included preoperative creatinine level greater than 1.5 mg/dl, emergent operation, ruptured aneurysm, intraoperative hypotension, total cross-clamp time greater than 100 minutes, cross-clamp time to the first kidney greater than 60 minutes, and postoperative RF. After logistic regression analyses, the presence of intraoperative hypotension (OR, 12.2; 95% CI, 3.5 to 43; $p < 0.001$) and postoperative RF (OR, 9.1; 95% CI, 2.5 to 33; $p < 0.005$) were independently associated with perioperative death.

DISCUSSION

Contemporary reports that detail renal function after TA aortic surgery are summarized in Table VII. Varying definitions and criteria have been applied for RF, and the data presented herein confirm that a clinically insignificant elevation in creatinine level occurs in virtually all patients. In this study, half of the 183 patients encountered a transient rise in their creatinine level with no more than a 50% elevation that invariably fell back to the baseline level. The peak creatinine level occurred at a mean of approximately 60 hours after operation for all patients. The incidence of RF in this study was 11.5%, with 2.7% requiring dialysis. Contemporary reports have documented an incidence of renal failure between 9% and 40%, depending on the series and the definition of RF (Table VII). The need for dialysis, which may represent a more objective sign of RF, has been documented in between 2.7% and 27% of patients in these same series.

The importance of RF after complex aortic surgery relates to the fact that patients who have this complication have significant increases in postoperative mortality risk. In this study, patients who had RF were nearly 10 times more likely to die in the perioperative period when compared with those without RF. This concurs with the findings of other series, and the data are even more convincing in patients who need postoperative dialysis support, with in-house mortality rates between 50% and 70%.[2,5] Schepens et al.[14] found that RF after TAA repair increased both short-term and long-term mortality rates; the 5-year survival rate for the patient group with kidney failure was 20% versus 62% for the patients without RF. For the same subgroups, Svensson et al.[1] found the late survival rates to be 30% and 66%, respectively.

Among preoperative variables that are associated with an increased risk of postoperative RF, baseline renal dysfunction has been an important factor both in this series and in others in which this information is available. Safi et al.[11] found that the degree of RF was increased with a preoperative creatinine level greater than 2.8 mg/dl. On logistic regression analyses, Schepens et al.[14] found that the two variables that were the most predictive of postoperative dialysis were an elevated preoperative creatinine level and increasing age. In this study, we found a weak association with age greater than 70 years to postoperative RF. Aside from that, the dominant intraoperative factors that led to an increase in postoperative renal dysfunction were intimately related to ischemic damage to the renal mass, specifically, the length of aortic cross-clamp time and intraoperative hypotension. Increased total aortic cross-clamp time is associated with postoperative RF likely because of increased acidosis, peripheral reperfusion injury, and release of cytokines. These data are in concordance with previous studies from Svensson et al.[12] that showed preexistent renal dysfunction and markers of hemodynamic instability to be significant independent predictors of acute RF. However, our data failed to show a significant association with RF for other variables that were examined, most notably emergent (vs elective) operation and ruptured aneurysm (16 of the 20 who underwent surgery emergently). We postulate that these patients "select" themselves out by remaining hemodynamically stable enough to eventually undergo definitive repair.

Strategies to prevent postoperative RF are based on recent studies that have further elucidated pathophysiologic mechanisms of RF. During thoracic aortic cross-clamping, there is a consistent hemodynamic response with severely decreased renal perfusion and glomerular filtration, as well as increased renal vascular resistance.[15] Furthermore, alterations in humoral factors, especially the renin-angiotensin system, exacerbate the renal injury during cross-clamping. Pretreatment with angiotensin converting enzyme inhibitors has shown some promise in animal studies, but human trials have not shown a consistent benefit.[16] It is believed that ischemia-reperfusion injury plays a central pathogenetic role in the patients we clinically describe as having acute tubular necrosis.[15] In this regard, the use of diuretics, especially mannitol, appears to be associated with a decrease in renal oxygen demand and thus protective to the kidneys from ischemic insult.[17]

Other strategies to prevent postoperative RF after complex aortic repair have included the evaluation of different intraoperative adjuncts. Specifically, RACP has been used by many, but its benefit remains controversial. Experimental evidence and data from the renal transplantation literature reveal an amelioration of the warm ischemic damage to the kidneys using renal hypothermia.[18,19] A small group of our patients underwent renal parenchymal temperature measurement during the early usage of RACP. In this limited experience, the patient's core kidney temperature drops to 15° C after bolus infusion of RACP and is maintained in the range of 24° C during drip infusion. Svensson et al.[12] initially reported results that indicated that the use of renal artery perfusion with cold Ringer's lactate solution did not appear to significantly avert the complication of acute RF. More recently, the same group found that the use of renal artery perfusion reduced the risk of RF in a more select group of patients.[20] Other studies have concluded that the evidence that shows the benefit of RACP is lacking in those patients who undergo TAA repair with either clamp-and-sew or left heart bypass grafting technique.[21] The benefit of RACP could not be statistically validated when comparing the group of patients who had postoperative RF in this study and the group of patients who did not. But the 21% of patients who did not receive RACP had either: (1) inaccessible renal arteries as a result of the extent of aortic repair (i.e., type I TAA); (2) very brief clamp times (i.e., <40 minutes), thus decreasing their risk for postoperative RF; or both. Clearly, prospective studies with patients equally stratified by baseline level of renal function would be needed to definitively answer this question of whether RACP is beneficial.

A comparison of RF in this series to those wherein distal aortic perfusion (versus the clamp-and-sew technique) is used does not reveal any significant differences.[22] Safi et al.[11] found that RF was increased with preoperative creatinine greater than 2.8 mg/dl, left renal artery reattachment, visceral perfusion, and simple clamp technique (as opposed to distal aortic perfusion) in a multivariate analysis. Some of these factors are counterintuitive and presently remain unexplained. The detrimental effect of visceral perfusion with a centrifugal pump was postulated to be the effect of nonpulsatile warm blood bathing the renal mass during the cross-clamping or the increased complexity of the procedure requiring atrial cannulation, leading to a deleterious effect. Interestingly, in this study, distal aortic perfusion was not found to have a similar deleterious effect.

Although not clearly proven by this retrospective study, our data indicate that adherence to the operative principles of an expeditious operation, minimizing clamp times, and regional hypothermic renal perfusion have produced favorable results with respect to renal dysfunction after TA aortic surgery. Prospective evaluation of newer adjuncts should be directed towards patients who have preoperative renal insufficiency because they are at highest risk for postoperative RF.

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DISCUSSION

Dr. Dhiraj M. Shah (Albany, N.Y.). It is my privilege to discuss this paper about the management of TAA in a large number of patients. I'd like to congratulate Dr. Kashyap and the group from Massachusetts General for their presentation of an excellent series with optimal outcome after TAA repair. Repair of TAAs is associated with three main controllable risks: RF, coagulopathy, and paraplegia. Here the authors address the mechanism of one such complication, that is, RF.

By using factor analysis, the authors tried to predict the potential for RF and its relationship to death after TAA repair. Postoperative RF correlated with preoperative renal impairment, prolonged aortic cross-clamp time vis-a-vis intraoperative ischemia and hypotension. Hypotension will also further increase intraoperative renal ischemia. Interestingly, RACP did not prevent RF in spite of conclusions that it might have helped. All patients showed renal dysfunction after surgery; whether or not they went into RF depended on their preoperative renal function. When RF did occur, the rate of fatality was high.

Of the factors that contributed to postoperative RF, the preventable factor was the cross-clamp time or ischemia. Therefore, intraoperative ischemia should be minimized at all costs. The philosophy of a quick clamp-and-sew technique may favorably control the outcome in most cases. But in difficult thoracic aortic aneurysm repair, when more time may be needed, one might consider either a shunt or some kind of a bypass procedure to prevent RF and also paraplegia. We have now used an internal bypass shunt from the thoracic aorta above the aneurysm to the visceral arteries before cross-clamping so that the operation can be done ad lib while virtually eliminating any ischemia to the visceral aorta and the spinal cord.

I would like to ask a few questions of Dr. Kashyap. Because RACP does not protect the kidney in your series but adds extra time and maneuvering, is it worth trying to do? It is usually recognized that trying to cool the kidney in vivo is almost impossible, and your series shows that.

You did not mention anything about the incidence of coagulopathy in this series. Was intraoperative hypotension, which was associated with death, caused by coagulopathy? What did you do to correct it?

You alluded in your discussion to the use of an internal shunt. Now that your series shows that if the cross-clamp time is high, more than 100 minutes, then RF may be a factor. Would you consider now modifying your philosophy of a quick clamp-and-sew technique to the use of some kind of shunt or bypass?

Dr. Vikram S. Kashyap. I thank Dr. Shah for his insightful comments and his questions.

With regard to the RACP, you are correct in that the univariate analysis did not show a benefit from using cold perfusion between the patients in whom it was performed and those in whom it was not. However, these groups are not equal. We tried to use RACP in almost all of the patients, and that occurred in 79%. The 21% who did not undergo RACP did not for one of three reasons: (1) the patient had inaccessible renal arteries; (2) the patient had a very brief cross-clamp time, in the order of about 30 to 40 minutes; or (3) they underwent visceral endarterectomy as an adjunctive procedure, and there was the concern of dissection with placing the catheters in.

Other large reviews by Svensson et al., Safi et al., and Schepens et al. all have produced conflicting results as to whether cold renal perfusion is of value. Specifically, Svensson et al. originally found it to be not of value, but later, selecting patients that had mesenteric occlusive disease and renal vascular disease did find it to be of benefit on a multivariate analysis. Clearly, what is needed is a prospective trial to answer the question. And perhaps given all of these conflicting results, that would be warranted to see whether RACP should be used. We, however, could not identify any deleterious effects from using it.

In a few of our patients at the very beginning of the series, a thermistor was placed and core parenchymal temperature was measured. This temperature dropped down to 15° C after bolus infusion, and during the continued infusion remained at a level of 24° C; thus we felt confident that we were achieving renal hypothermia during the cross-clamp time. Furthermore, both the transplant literature and some of the nephrology literature show theoretical benefits. The addition of mannitol seems to, in experimental models, alleviate some of the renal ischemia, oxygen demand, and renal vasoconstriction that does occur. Furthermore, in the transplant literature, renal hypothermia, usually in an ex vivo setting, has been also shown to ameliorate renal function after surgery.

Dr. Shah, in regards to your second question, regarding coagulopathy, there was a single patient who had intraoperative bleeding that could not be staunched, and this patient died. Dr. Cambria actually presented a more comprehensive review at the American Surgical this year that included factors like coagulopathy and paraplegia.

Lastly, the very interesting question of whether bypass is useful. First, I will say that in my last comparison slide all of those series were using clamp-and-sew technique. And the necessity for dialysis ranged from 2.7% to 27%. We also reviewed other papers that used partial left heart bypass—that is, cannulating the left atrium and performing distal aortic perfusion—or other methods, and their rates of dialysis were either the same or higher than what we have presented here. It makes intuitive sense that restoring pulsatile flow to the renal arteries should prevent RF; however, specifically using distal aortic bypass grafting with left atrial cannulation and having nonpulsatile flow does not seem to ameliorate postoperative RF. This may be a result of the activation of the renin angiotensin system, as postulated by Safi and his colleagues.

We have been using recently an in-line mesenteric shunt, which is an 8-mm Dacron graft that is sewed onto the proximal part of the aortic graft. After the proximal suture line has been completed, this chimney stack, if you will, has cannula that are inserted into the superior mesenteric artery or the celiac artery, providing pulsatile flow. Perhaps a modification of this could be inserting cannulas into the renal artery orifices as well to provide oxygenated pulsatile aortic blood flow down to the renal arteries while the rest of the operation is completed.

Dr. Henry D. Berkowitz (Philadelphia, Pa.). This is a very nice paper, but I am disappointed because I thought I was going to learn that RACP with cold perfusate was going to be helpful. I have always questioned its value, because it is so difficult to cool a kidney that remains in situ unless one uses high flow rates and large volumes of fluid. You indicated that some perfused kidneys were actually cooled to 15° C; I would be interested to know how much perfusate was used to accomplish this, and how long hypothermia lasted. Do you think that some renal protection is provided by the prednisone and mannitol in the perfusate even in the absence of hypothermia?

The other point of some interest is your finding that when the clamp time until perfusion of the first kidney was greater than 60 minutes, the mortality rate was higher. However, because the right renal artery, celiac artery, and superior mesenteric artery are usually sewed on as a single patch, is it possible that the mortality rate may be more related to visceral ischemia and not just renal ischemia?

Dr. Kashyap. Thank you, Dr. Berkowitz. In terms of the RACP, we gave a bolus of 250 ml after opening the aorta and then continued a drip installation, the total volume probably not exceeding about 500 to 600 ml. We did not get systemic hypothermia with those volumes.

In terms of the cross-clamp time to the first kidney greater than 60 minutes, it was associated with perioperative death, but it wasn't associated with RF. And I agree with you, in almost all of these cases the right renal orifice was the first one perfused, and that was in a button that included the mesenteric vessels. So clearly there could be some confounding deleterious effect from revascularizing the intestine that we are not sorting out or identifying.

Dr. Anton N. Sidawy (Washington, D.C.). Did you look for any correlation between the site of the suprarenal clamp and the onset of RF? You mentioned that there were some aneurysms that were just suprarenal and others were TA.

Dr. Kashyap. We divided the groups into type 1 and type 2 TAAs versus all others. And in that analyses, type 1 and type 2 did not seem to increase the risk of either RF or perioperative death.

Dr. Paul Haser (Newark, N.J.). You mentioned that intraoperative hypotension was found to be a significant factor. Please elaborate on whether this intraoperative hypotension was related to anastomotic leaking or whether it occurred when the vascular beds were reperfused? Do you have recommendations of steps we might take to avoid the intraoperative hypotension?

Dr. Kashyap. There were a variety of causes for the intraoperative hypotension, and we defined that as a systolic blood pressure of less than 70 mm Hg for a prolonged period of time. Pharmaceutical measures obviously were instituted during that time by our anesthesia colleagues, but the sources of the intraoperative hypotension included bleeding, cardiogenic sources, as well as reperfusion of the mesenteric bed in a few of those patients. But mostly it was from bleeding or cardiogenic reasons.

Dr. Brooke Roberts (Bryn Mawr, Pa.). I have a question about your criteria as to when you use dialysis. I noticed that 11% of these patients went into RF and yet only five underwent dialysis. Are they a little higher than usual, or why didn't you dialyze more?

Dr. Kashyap. Thank you very much. Again, of those 21 patients who did have significant RF, five required dialysis and 16 had acute RF, of which most recovered. The patients who underwent dialysis had progressive elevations in their creatinine level, metabolic disarray, or volume disturbance that required dialysis. All of these 21 patients, and more, I should say, were also followed by the nephrology service, and the necessity for dialysis was determined by their criteria.

Dr. R. Clement Darling (Albany, N.Y.). You had a significant amount of renal artery stenoses, especially bilateral stenoses. How were they handled during the operation?

Dr. Kashyap. The left renal artery in about 85% of the patients had a side-arm 6 mm polytetrafluoroethylene graft that was bypassed past the orifice. So for the left renal artery it was fairly straightforward.

In the right renal artery, on the other hand, there was a small percentage of patients who underwent endarterectomy. And I must say that the renal artery stenosis was a preoperative designation that was found on angiograms that showed a >50% stenosis. However, during the operation, if it seemed like the orifice was patent and was not of concern, it was not tackled.